Weak Lensing and Redshift Surveys

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Outline

1. WL Programs and the Need for Redundancy
2. A Redder Redshift Survey?

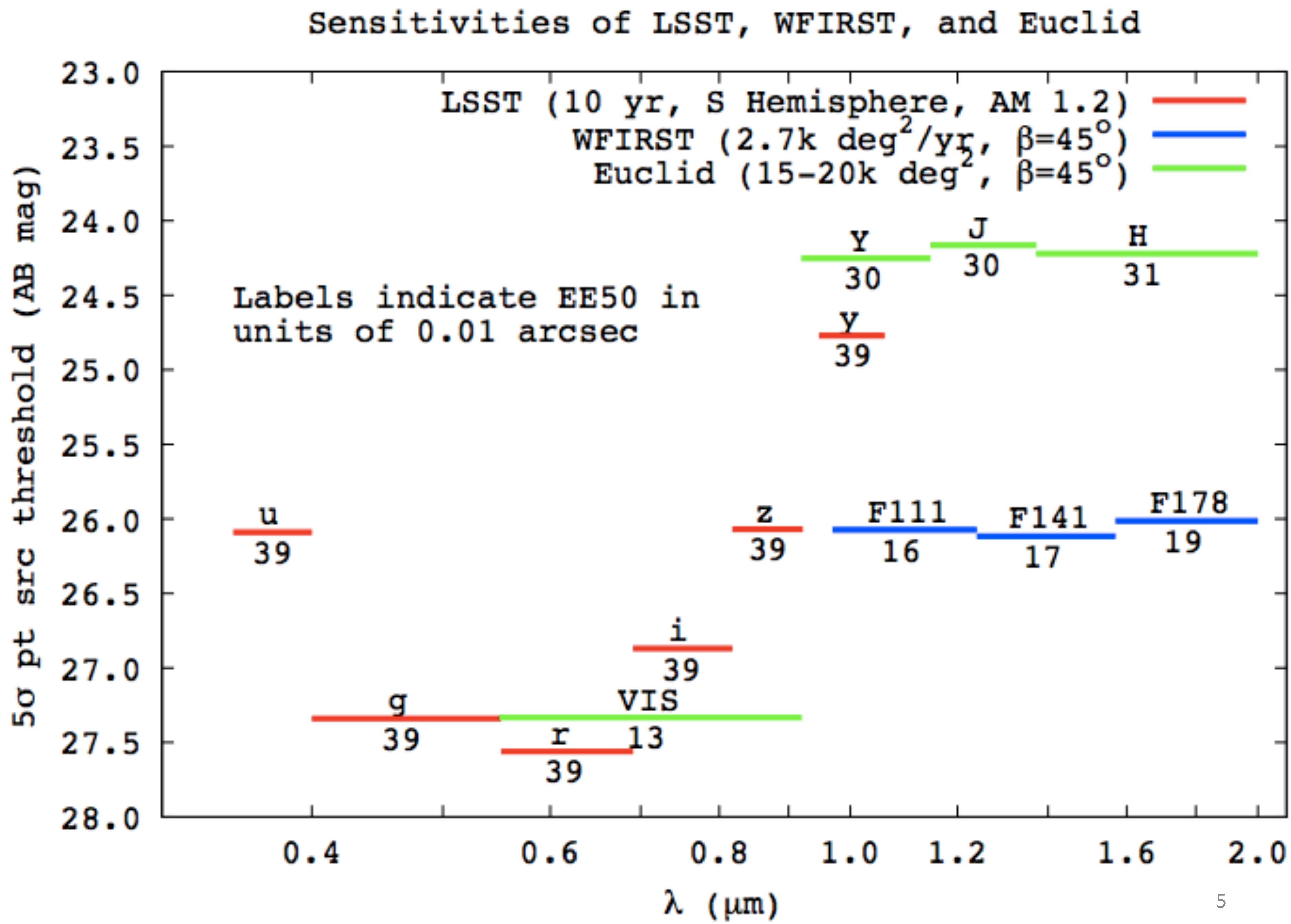
What is needed for a WL program?

- Statistics
  - “Stage IV,” within a factor of a few of cosmic variance.
- Shape Measurement
  - Resolve and fully sample galaxies, high S/N
  - Accurate knowledge/correction of PSF + detector effects
  - Power/cross spectra from multiple redundant subsets of the data (for cross checks internal to WL method).
- Photometric Redshifts
  - Required both to measure signal(z) and suppress intrinsic alignments (needs low outlier fraction)
  - Photometric data points from *u*—H bands.
  - Calibration sample (with massively multiplexed spectrographs).

- ***There may be some substitutability on these points (e.g. outside OIR bands), and some fractions of the program are possible with subsets of the data. However we can’t skimp on a requirement just because it’s hard.***
- ***There is no requirement to do all of this from the same platform. No one of LSST, WFIRST, or Euclid is a complete program by itself!***

This is really hard.

- Currently, can barely control systematics with smaller datasets.
  - Some of the big recent surveys are statistics-limited at N_{gal} ~ few M … with years of effort.
- Need to measure shear with really small biases:
  - Typical specification is on c,m where: $\boldsymbol{\gamma_{meas} = (1+m)\gamma_{true} + c}$
- For Stage IV: need $c{\sim}2{\times}10^{-4}$, $m{\sim}10^{-3}$.
  - So far the community's big problem has been additive bias (c)
  - But as we go to larger area, m is just as hard
    - Has to be calibrated from simulations
  - Requirement[c] ~ $\mathbf{Area^{-1/4}}$ but Requirement[m] ~ $\mathbf{Area^{-1/2}}$
- Cross correlations of data sets: A×B
  - If the systematics are independent, can suppress additive systematics
    - A **very** powerful technique!
    - But beware of subtle correlations (used same PSF stars, photo-z's, etc.)
  - The multiplicative systematics remain
    - The "effective" m is $(m_A+m_B)/2$.



Sensitivities of LSST, WFIRST, and Euclid
LSST (10 yr, S Hemisphere, AM 1.2)
WFIRST (2.7k deg^2/yr, β=45°)
Euclid (15-20k deg^2, β=45°)
Labels indicate EE50 in units of 0.01 arcsec
5σ pt src threshold (AB mag)
λ (μm)
u 39
g 39
r 39
i 39
z 39
y 39
VIS 13
Y 30
J 30
H 31
F111 16
F141 17
F178 19

Imaging Capabilities

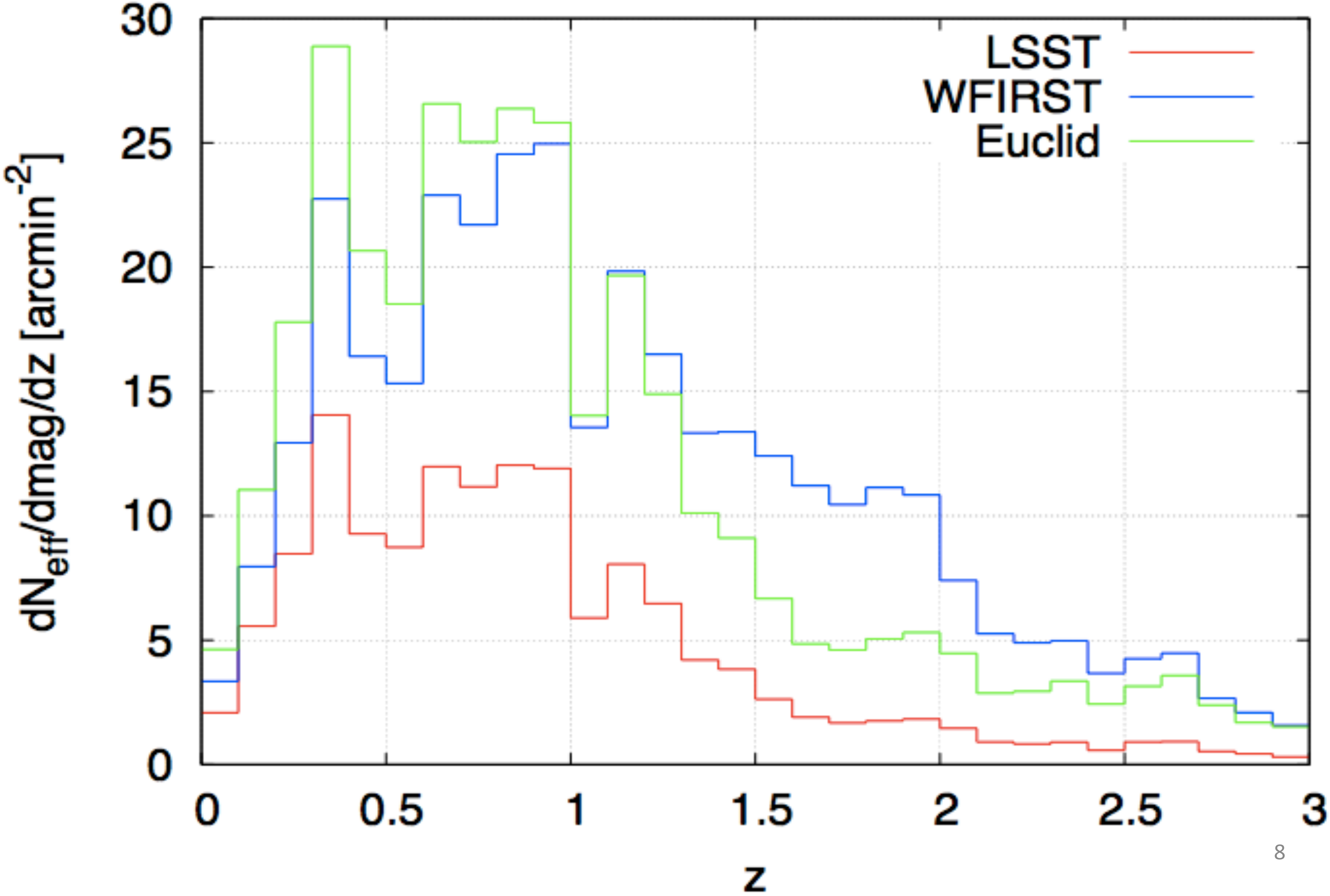
- Each of the 3 surveys provides a unique imaging capability.
- LSST:
  - 6 band optical imaging; time domain
- WFIRST:
  - Deep, high resolution NIR imaging (fully sampled in 2 of 3 bands)
- Euclid:
  - High resolution optical imaging (highest resolution of the 3 surveys)

WL Capabilities

	LSST	Euclid	WFIRST
Area [deg^2]	~12,000 (S Hemisphere)	≥15,000	2,700 (1 year)
Source density n_{eff} [gal am^{-2}] Res>0.4, S/N>18, σ_e<0.2	14	33	35 (union catalog) 30 F141 + 32 F178
Median z	0.80	0.84	1.02
Shape measurement filter	r & i	VIS (550—920 nm)	F141 & F178
Detectors	CCD	CCD	HgCdTe
Photo-z filters	6 (ugrizy)	4 (VIS + YJH)	3 (F111/141/178)
Location	Ground	Space	Space
Exposures in filled shape survey	~700× 15 s (r+i)	3× 600 s	10× 160 s (5+5)

Number densities based on the COSMOS Mock Catalog – S. Jouvel et al (2009)

Redshift Distributions

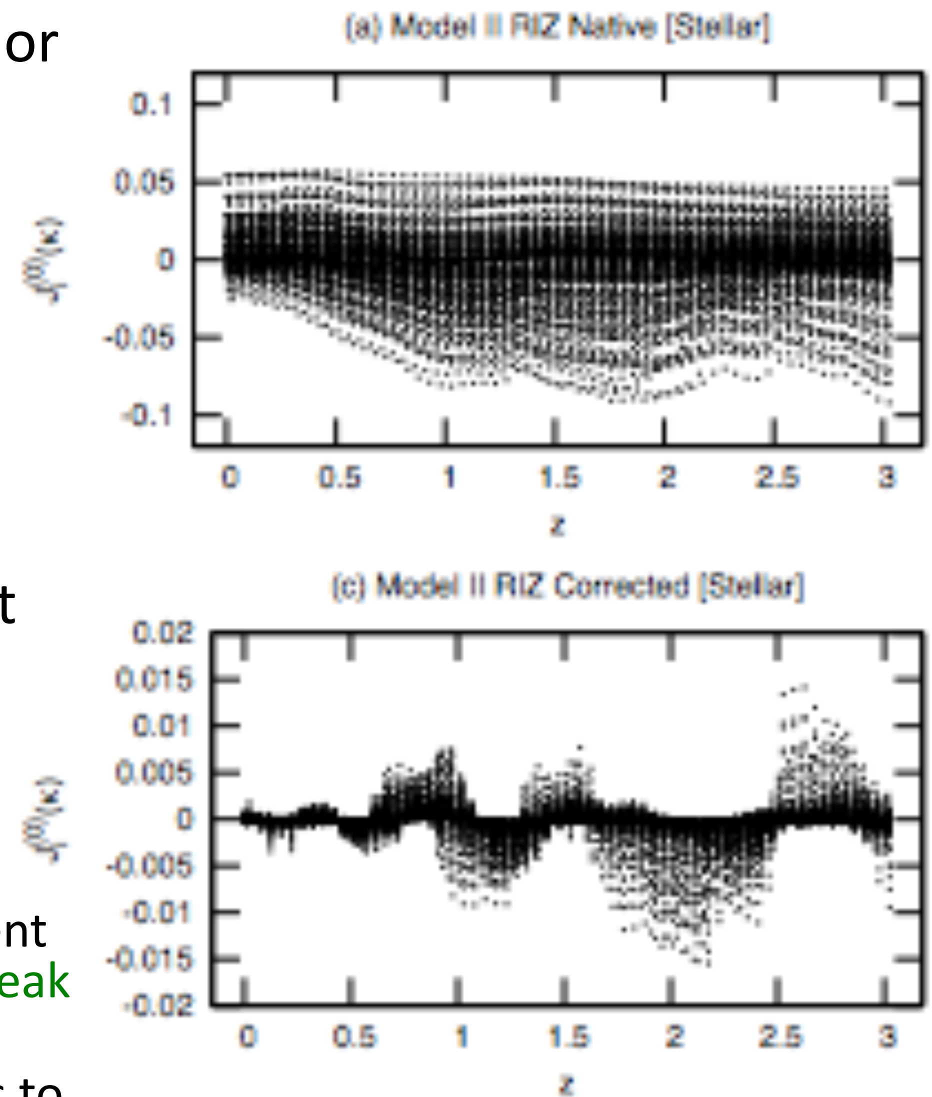


Sampling Considerations

- All of the proposed space missions achieve full sampling through dithering.
  - Depends on number and spacing of positions and sampling parameter $Q = [\lambda_{min}/D]/[\text{pixel scale}]$.
  - Q>2 for full sampling at native scale.
  - With unobstructed telescope, can combine rolled images as well.
- Implementations
  - Q = 0.94 for Euclid VIS, 1.11 or 1.41 for WFIRST bands
  - 3—4 positions for Euclid, ≥5 per filter for WFIRST
  - Simulations (thanks to Barney Rowe) indicate that a fully sampled reconstructed image is possible in both cases
    - For Euclid @ 0.55 μm, band limit is charge diffusion not diffraction
  - WFIRST has more margin – survives 1 CR hit even at "floor" coverage.
  - **CRs not trivial**: if $5/cm^2/s$ and r_{cut}=3 pix, kill rate is 54% of Euclid galaxies in 3-dither region vs 7% for WFIRST. (Not in current forecasts.)

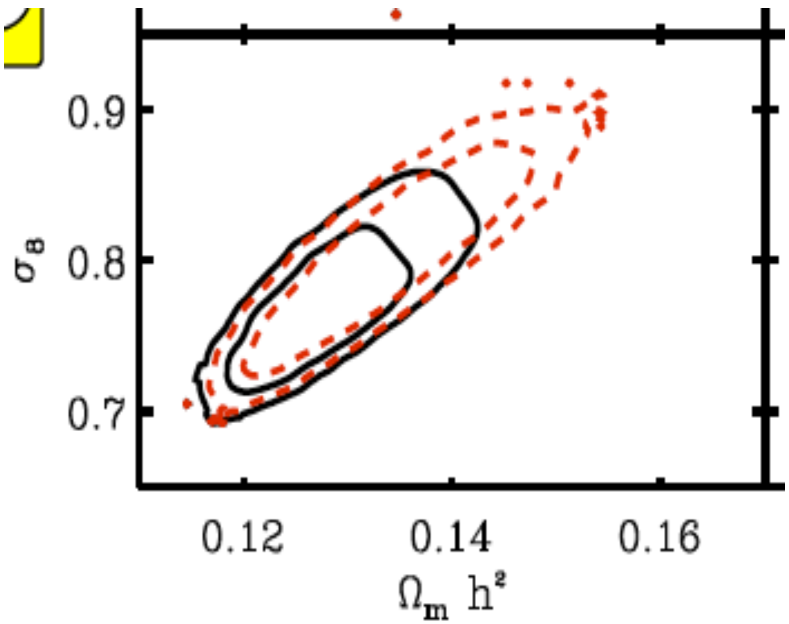
Colors

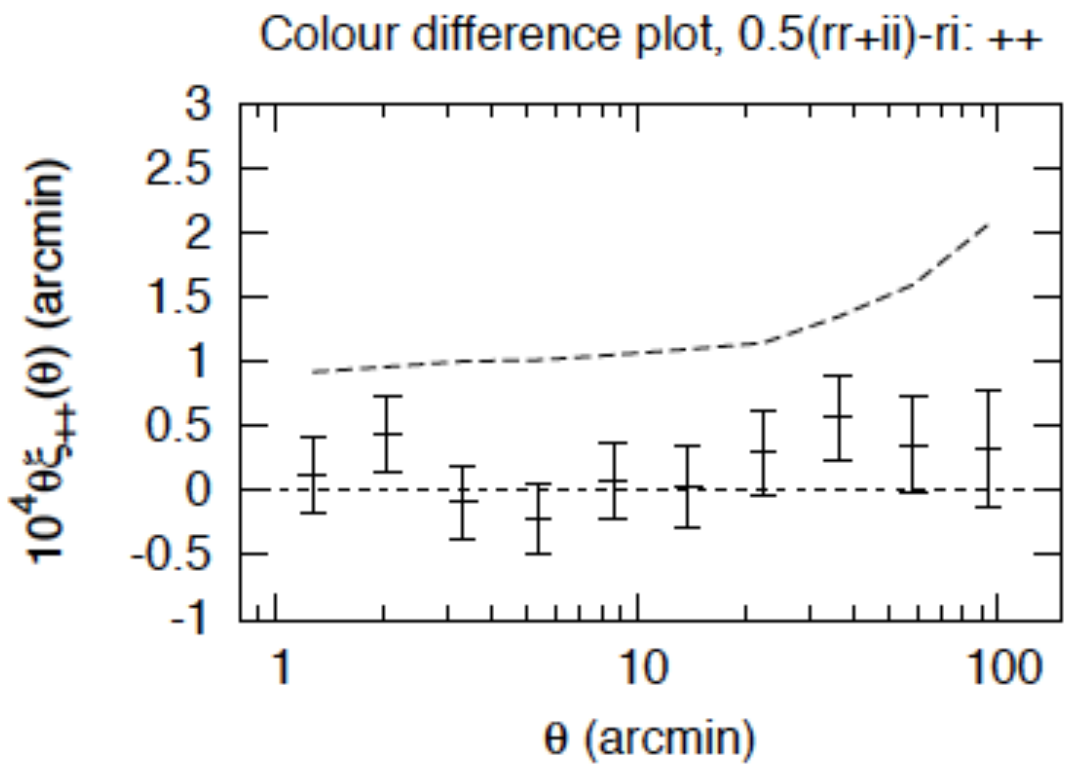
- Color dependence of PSF is a major issue since it causes stars and galaxies to have *different* PSF!
  - Biases are easily several %.
  - Complex z dependence.
  - Airy worse than Gaussian.
  - Equivalent to (u,v)-dependent bandpass.
- Would like to correct at least the continuum on an object by object basis.
- Need multiple survey filters to check whether the correction is "right".
  - Nastiest color dependence is different in optical vs NIR – Balmer/4000Å break vs Hα+[N II] complex.
  - 3 filters (VIS+F141+F178) enables us to "dodge" particularly nasty features.



Internal Checks

[Huff et al 2011 – SDSS]





Dashed lines are statistical errors.

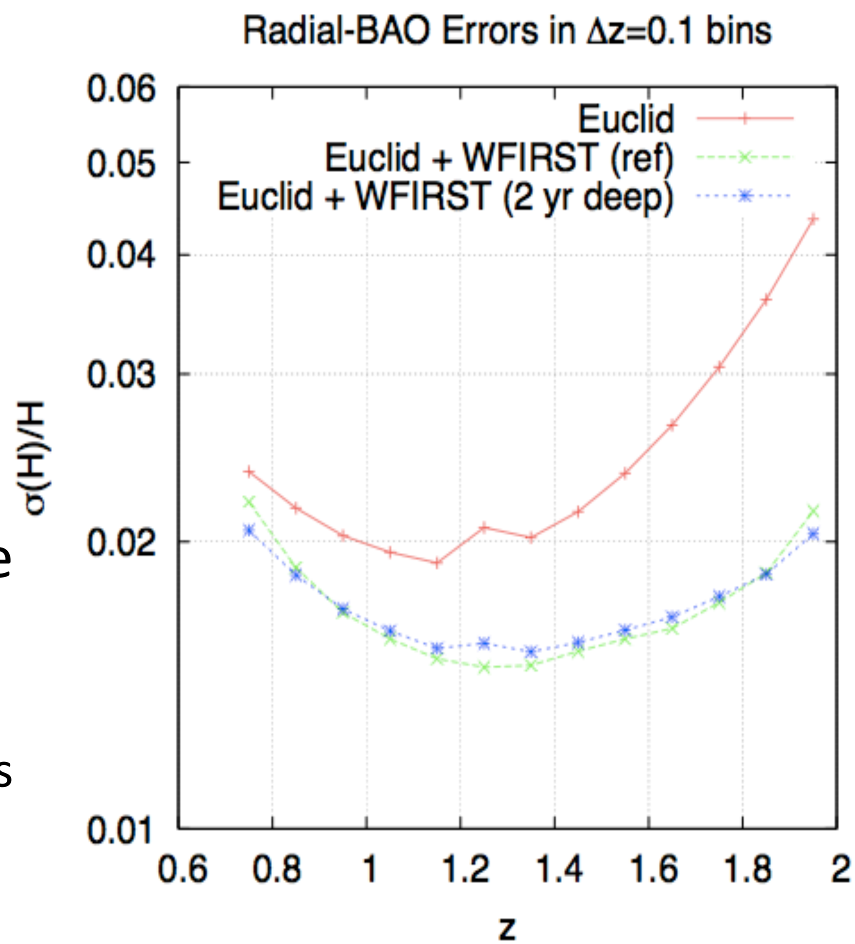
Data points are difference between auto vs cross correlations (should be 0).

Redundancy Considerations

- Need to generate redundant data subsets as a cross check of the power spectrum.
  - The credibility recent results [see e.g. Huff et al '11] would have been much harder to establish without this test.
  - Maybe more important than better statistics? In a systematics limited subject, redundancy is good and greed is not good.
- Several implementations possible.
  - The WFIRST baseline plan is to do the WL survey twice, once in each filter (F141 vs F178) and with the tiling pattern rolled. Severe sacrifice in area to make this possible.
  - Euclid baseline plan is 1 survey but can add something else. Remember: our goal is to accomplish the science, including cross-checks, with the union of all the data.

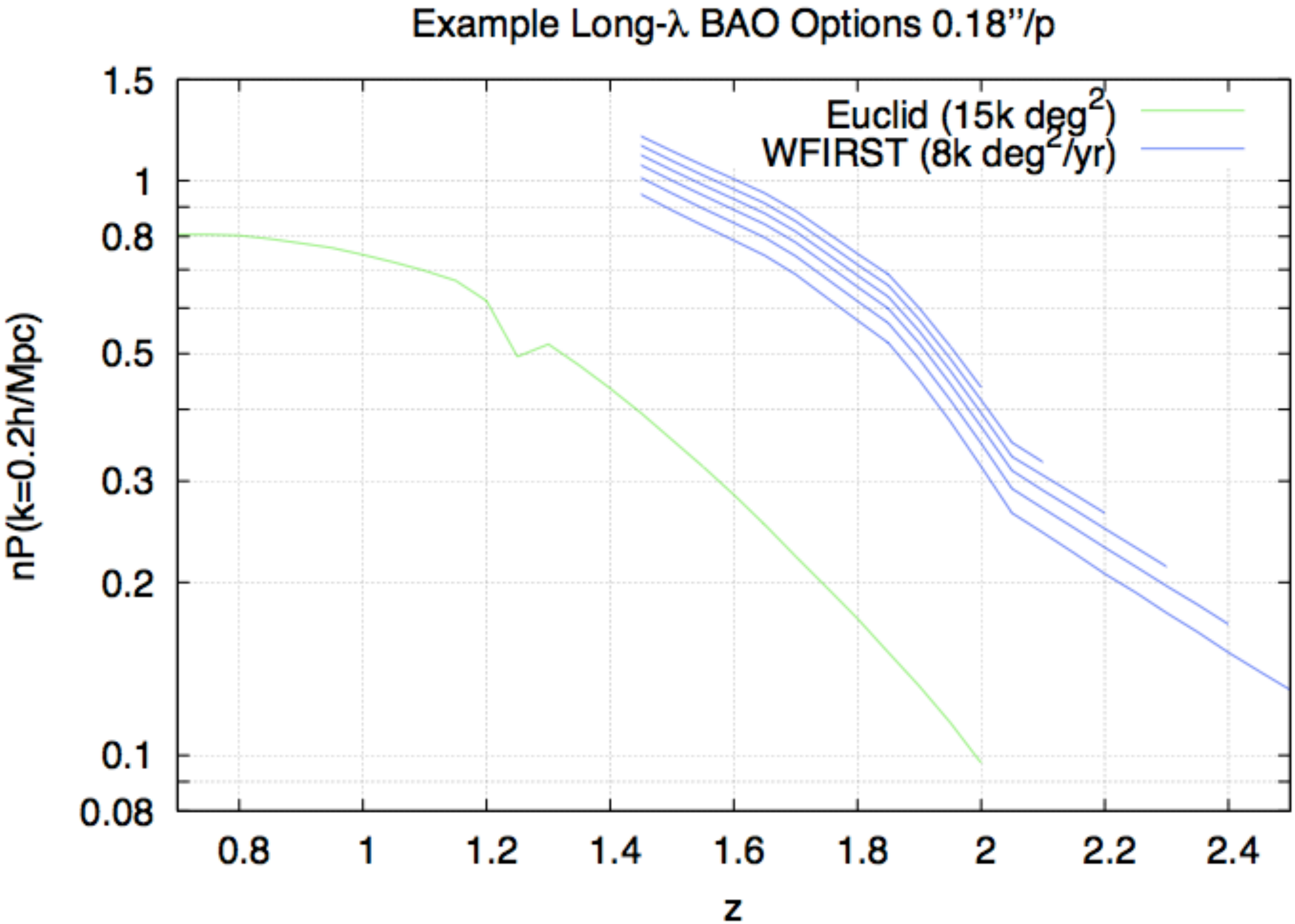
Notes on BAO Surveys

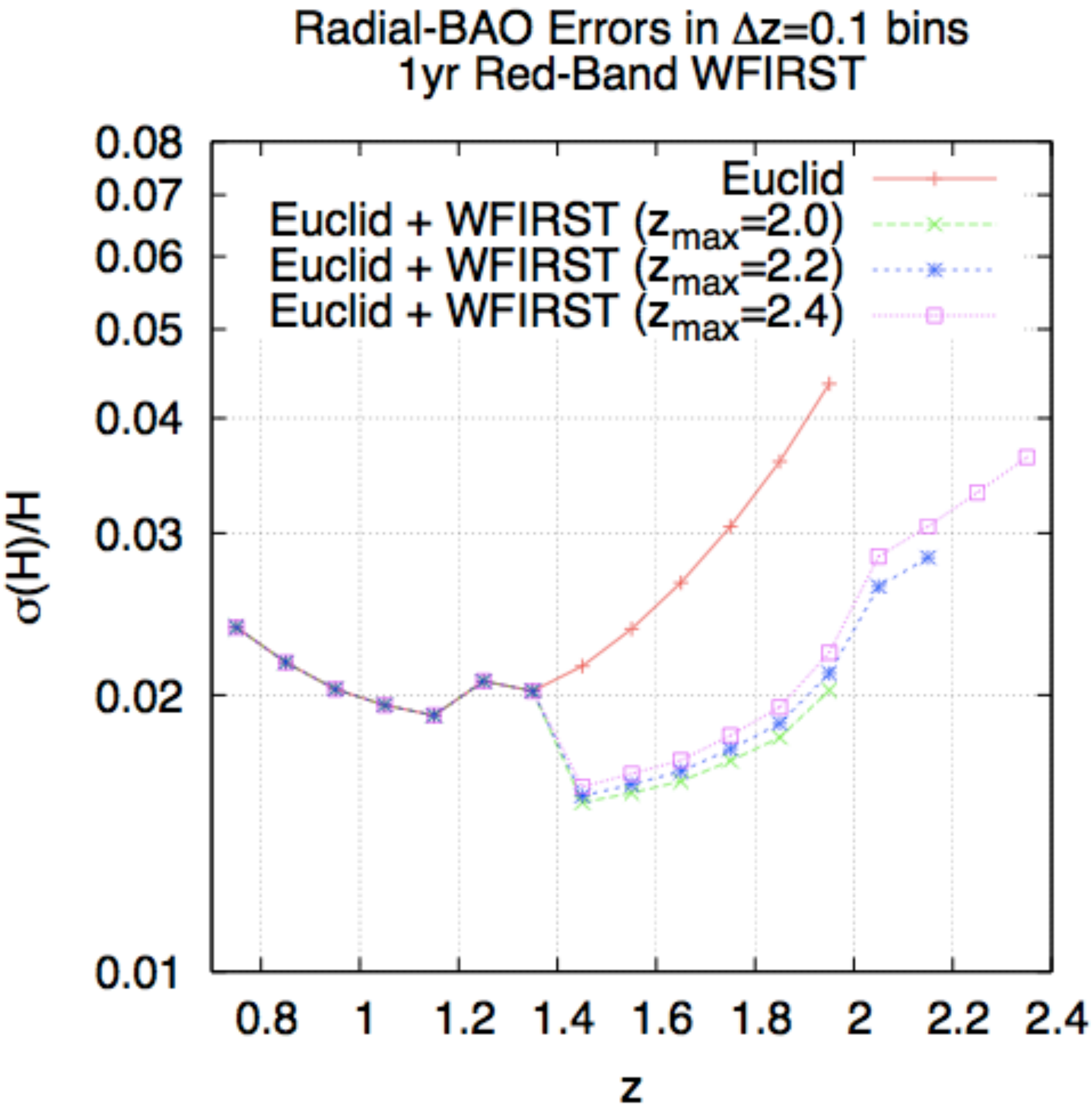
- Euclid provides a capable BAO survey (also slitless NIR-Hα)
  - WFIRST split BAO into "Deep" (parallel to NIR imaging survey) and "Wide" (BAO only) parts
  - Euclid similar to WFIRST wide (11k deg^2); slightly wide/shallower, but covers the available low-zodi sky.
- But with Euclid, it might make sense to move WFIRST BAO to all-Deep mode (at fixed observing time).
  - A wash for BAO (see right), but benefits imaging (2× coverage) and eliminates one observing mode.
- **This is just a possible example assuming no hardware changes.**



What if BAO Goes Redder?

- Starting Assumptions:
  - 0.18”/p, 7x5 H2RG single-channel
  - 1.3 m aperture, 4% cold mask vignetting
  - 3 μm diffraction limit
    - Assumed pure coma (worse than focus, astigmatism, trefoil)
    - At smaller pixel scale this is a significant sacrifice, may want to revisit
  - Telescope T = 220 K + 5 K margin
  - Same throughput curve as IDRM1-SpC
  - Exposure time of 5x200 s
  - In plots with Euclid, assume overlapping areas.
    - Euclid will already have covered the prime real estate.
- Considered z_{min} = 1.4, z_{max} varied from 2.0—2.5.
- These need refinement – just a first pass!
  - And don’t forget we would need a prism design that can actually do this.


Example Long-λ BAO Options 0.18''/p
Euclid (15k deg^2)
WFIRST (8k deg^2/yr)
nP(k=0.2h/Mpc)
z
1.5
1
0.8
0.5
0.3
0.2
0.1
0.08
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4


Radial-BAO Errors in Δz=0.1 bins
1yr Red-Band WFIRST
Euclid
Euclid + WFIRST (z_{max}=2.0)
Euclid + WFIRST (z_{max}=2.2)
Euclid + WFIRST (z_{max}=2.4)
σ(H)/H
z
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4

Comments

- The high z BAO program would probably benefit from deeper/narrower strategy.
  - Should revisit with "realistic" throughput.
  - Explore other trades, e.g. at z_{max}=2.4:
    - Raising z_{min} from 1.4→1.7 leads to 1.34x nP
    - Tightening WFE budget to 2.5 μm diffraction limit leads to 1.18x nP
  - But given Lyman-α forest, you would probably not spend WFIRST time on this for BAO alone.
- The primary motivation for doing this survey would be the RSD.
  - This program is **not** possible with Lyman-α forest (and probably not with LAEs).
    - IGM absorption equivalent widths don't add – Kaiser relation β=f/b does not apply even on linear scales, need hydro sims to interpret.
  - Work to do:
    - **Fisher forecasts for z~2 RSD program.**
    - **Quantify science opportunities for an overlapping ELG + LyαF survey.**